PERFORMANCE EVALUATION OF MODIFIED BITUMEN BINDERS WITH WASTE PET BOTTLES AND TIRE RUBBER POWDER

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Abstract - In this paper the utilization of waste PET bottles and waste tire rubber powder, along with virgin bitumen (VG40), for constructing low-budget roads is discussed as an alternative to conventional, expensive polymer modified bitumen (PMB). The increase in economic growth and changes in consumption and production patterns have led to the generation of various wastes, including plastic waste, tire rubber waste, fly ash, among others, polluting urban areas. In the current study VG40 is mixed with the two different polymer wastes i.e., PET bottles and rubber tire scrap powder. The preliminary tests were conducted on VG40 mixed with 2, 4, 6, 8, 10% of combined waste. The study demonstrates that adding 6% waste by weight to hot 30/40 pen grade bitumen enhances stiffness, resistance to high-temperature deformation, elasticity, and cohesiveness at the micro level.

Key Words: VG40; Tire rubber; Waste plastic; Elastic recovery; PET bottles.

1. Introduction

The need for transportation has gradually increased in tandem with the growth of the global population. Highways are still the world's most frequently used transportation method for both passenger and freight transit since they provide access to almost everywhere. Unfortunately, the growing demand for transportation also has a negative impact on the speed at which roadway pavements deteriorate. Improving the quality of materials used to build roadways is the main strategy utilized to prevent pavement deterioration. Bitumen is a building substance used in flexible pavements as a binder. Depending on the temperature and vehicle speed, bitumen exhibits different behaviour. At high speeds and low temperatures, bitumen behaves more like an elastic solid.

Thermal cracks are the most common type of degradation that occurs under certain circumstances. Wheel tracking is the most frequent type of deterioration because bitumen behaves more like a viscous liquid at low speeds and high temperatures. Fatigue cracks are the most common form of breakdown when bitumen exhibits viscoelastic properties under typical ambient conditions and average speed values. Various studies have been conducted on the properties of hot-mix asphalt (HMA) used in flexible pavements. It is common to modify bitumen with polymer-based additives, and there are numerous studies on this subject in the literature. Waste thermoplastics are currently being investigated as an option for bitumen modification due to the high cost of polymer-based additives.

1.1 Previous Studies

Shamim. S. and Vikram. A. (2023) studied that the addition of Tio2 to the plastic waste samples led to further improvement in the values of both Marshall stability and indirect tensile strength. The optimal amount of Tio2 addition was found to be 1% of the total weight of the sample. Beyond this amount, the values of both Marshall stability and indirect tensile strength decreased.

Russo and Oreto (2022) use of plastic waste and jet grouting waste as fillers in the production of hot asphalt mastics. The results showed that plastic waste had the best environmental performance.

Vangari M. and Poloju K. K. (2022) polymer-modified bitumen in recycled asphalt pavement (RAP). The research involved conducting various laboratory tests by replacing bitumen with different polymers including polypropylene, polyethylene, and RAP material.

Karmakar. S and Roy. TK (2021), a waste fraction of 2 parts plastic waste, 0.25 parts polymer-modified bitumen, and 1 part crumb rubber powder in the hot mix asphalt. The second durability index (SDI) value for each sample was calculated by dividing the arithmetic sum of stability loss area by the entire period.

Mishra. B. and Gupta. MK. (2020) a mixture of bituminous concrete and shredded polyethylene terephthalate (PET). Three different sizes of PET content, ranging from 3% to 10% of bitumen composition (4.75-2.36, 2.36-1.18, 0.60-0.30 mm), were examined through tests including Marshall stability, flow value, and indirect tensile strength (IDT). The results showed that the modified bituminous concrete mix had improved Marshall stability and IDT, which increased its resistance to moisture as well as its resistance to deformation.

2. Experimental Program

2.1 Materials

Tire rubber scrap powder, which typically contains a higher amount of carbon black, is another modifying agent that can be obtained from discarded tires. Such tires are deemed unsuitable for use on vehicles due to wear or irreparable damage. Polyethylene terephthalate, commonly known as PET, is a versatile thermoplastic polymer that is widely used in various industries. Its production has grown rapidly over the years, with an annual production of 56 million tons in 2016. VG-40 is a type of bitumen with specific physical properties, suitable for use in high-stress areas such as intersections, toll plazas, and truck terminals. It is used in lieu of the 30/40 penetration grade of bitumen.

2.2 Preparation of Samples:

To investigate the properties of modified bitumen binders, various types of polymer waste were mixed with 300 grams of hot base bitumen at different weight percentages ranging from 0 to 10%. The mixture was then stirred for 45 minutes in a laboratory stirrer with three blades rotating at a speed of 4000 revolutions per minute. In total, 30 samples were prepared for the purpose of determining each property of the modified bitumen binder

Fig 1. Bitumen burning

Fig 2. Sample preparation

3. Methodology:

Table 1: Proposed plan of testing

Mixed Proportion (%age)	**A proper plan of testing in a laboratory**
Virgin Bitumen+ [Plastic waste+ RSP)	Softening point test, Penetration tests and elastic recovery test
100 + 0	
98 + 2	
96 + 4	
94 + 6	
92 + 8	
90 + 10	

Total 30 specimens were tested in the laboratory and testing was done as per IS 73:2013.

4. Results and Discussion

4.1 Penetration tests: Penetration test is the most commonly adopted test for bitumen to grade the material in terms of its hardness conducted as per IS 1203 (Bureau of Indian Standards 1978a). In this study, a penetration test was conducted on bitumen mixed with waste PET bottles and tyre rubber powder. The proportion of waste materials used was varied from 0% to 10%, with increments of 2%. In Table 2 and Fig 3, the results showed a decrease in the penetration value as the amount of waste material added to the bitumen increased.

Table 2. Material proportion (%) with penetration value (mm)

S. No.	Material Proportion (%)	Penetration Value (mm)
1	100	56.67
2	98:2	55.66
3	96:4	53.5
4	94:6	52.5
5	92:8	51
6	90:10	49

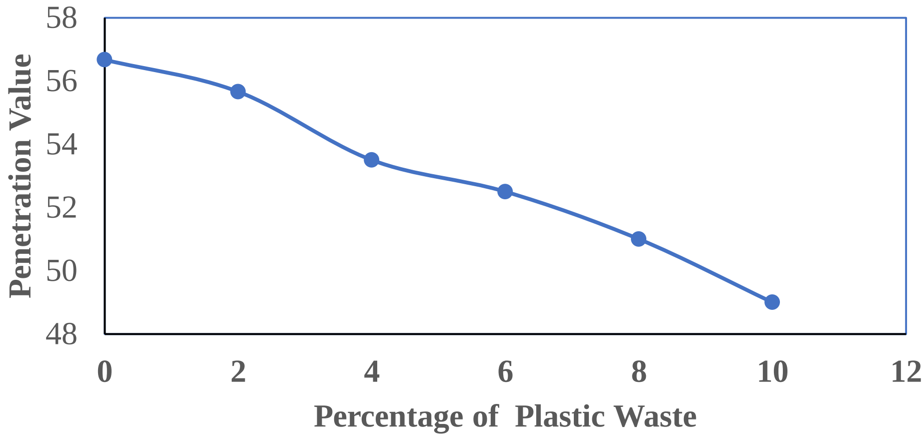

Fig 3. Penetration value vs Plastic waste

4.2 Penetration Index

The penetration index represents a quantitative measure of the response of bitumen to variation in temperature. The viscosity of bitumen is inversely proportional to the cube of its penetration value. This means that as the penetration value decreases, the viscosity increases. The original VG40 mixed with different percentages of PET bottle and tire waste calculated the penetration index values by using the equation (1) and values are presented in the Table 3. The obtained values of penetration index graphically presented in Fig 3 to understand the trend of penetration index while increasing the waste material (PET+ tire waste). From Fig 4, it explains the increasing trend of penetration index. The results are similar to the previous authors did the VG30 grade mixed with the similar composition.

[$$PI = \frac{1,952 - 500\log(Pen25) - 20*SP}{50\log(Pen25) - SP - 120}$$ Eq. [1]

Table 3. Percentage of added modifier (wt%) and Penetration Index

S.no	Percentage of added modifies (%)	Penetration Index
1	0	-1.8
2	2	-0.5
3	4	0.1
4	6	0.4
5	8	0.5
6	10	0.6

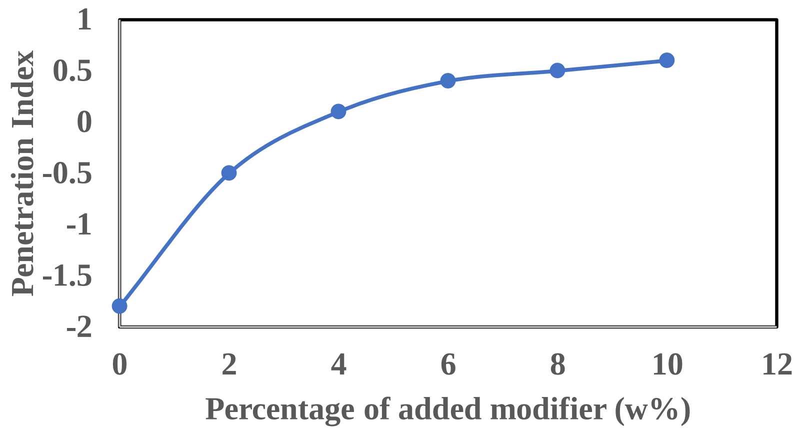

Fig 4. Penetration Index vs Percentage of added modifier (w%)

4.3 Softening Point:

For this study, performing softening test by using bitumen with waste PET bottles and tyre rubber powder. The present study use waste as a proportion of 0%, 2%, 4%, 6%, 8% and 10% and we found that the softening point increases when we add waste material in it. The addition of waste materials such as PET bottles and tire rubber powder to bitumen can result in an increase in the softening point of the mixture shown in fig 5.

Table 4. Material proportion with softening point value (^{0}C)

S. No.	Material Proportion (%)	Softening Point Value (^{o}C)
1	0	51
2	2	54
3	4	58
4	6	60
5	8	61
6	10	62

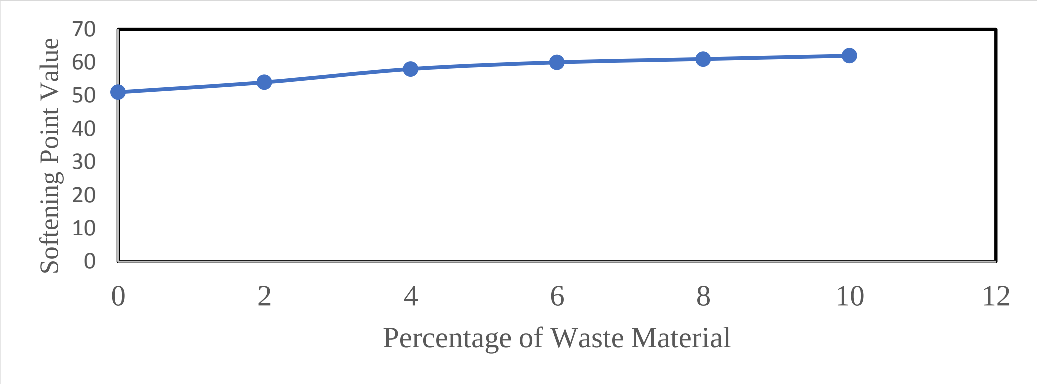

Fig 5. Softening point value vs Percentage of waste material

4.4 Elastic Recovery Test

The present study performs elastic recovery test by using bitumen with waste PET bottles and tyre rubber powder. The present study use waste as a proportion of 0%, 2%, 4%, 6%, 8% and 10% as shown in table 5 and we found that the penetration value increases when we add waste material in it. Adding waste materials, such as PET bottles and rubber tire powder, to bitumen can increase the value of elastic recovery as shown in fig 6.

Table 5. Material proportion (%) with Elastic recovery (%)

S. No.	Material Proportion (%)	Elastic Recovery (%)
1	100	25
2	98:2	25.5
3	96:4	25.5
4	94:6	25
5	92:8	24
6	90:10	21

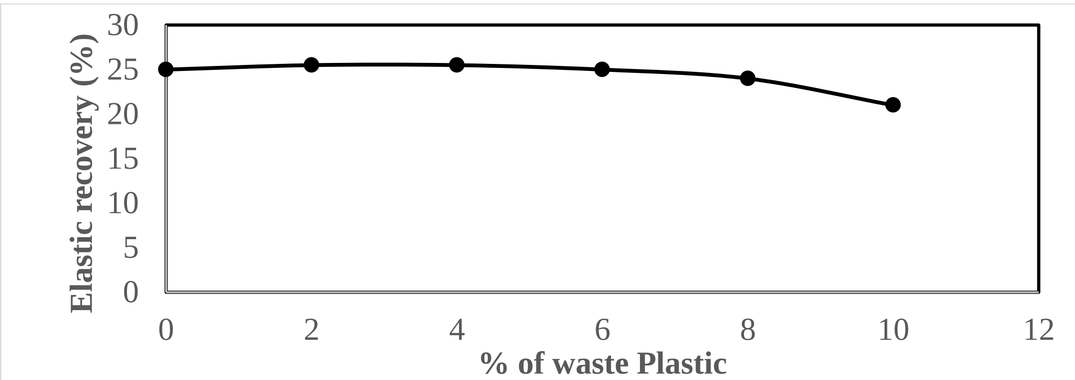

Fig 6. Elastic Recovery (%) vs Percentage of waste Plastic

Penetration test **Softening point test** **Elastic recovery test**

Fig 7. Testing of samples

4. Conclusion

This study evaluated the feasibility of using PET bottles and crumb rubber tyre wastes as an alternative polymer additive in bitumen modification instead of traditional polymers. The original VG40 grade bitumen mixed with the 0, 2%, 4%, 6%, 8%, and 10% of PET and crumb rubber waste and conducted the material testing. The following conclusions are drawn from the test results.

- When the virgin VG40 grade was mixed with PET and crumb rubber waste material at various percentages (2%, 4%, 6%, 8%, and 10%), the penetration value decreased.

- The addition of waste materials such as PET bottles and tire rubber powder to bitumen can result in an increase in the softening point of the mixture.

- Adding waste materials, such as PET bottles and rubber tire powder, to bitumen can increase the value of elastic recovery. The elastic recovery value is important for the durability and longevity of roads and other infrastructure, as it helps prevent the formation of cracks and potholes.

- The addition of waste materials like PET bottles and tire rubber powder to bitumen can lead to a decrease in the penetration index value of the resulting mixture. This decrease is due to the densification of the mixture, which limits the amount of penetration that can take place

- Hence, the utilization of PET bottles and tire rubber powder in bitumen VG40 can provide a twofold benefit. Firstly, it helps to mitigate the amount of these wastes in the environment. Secondly, it can enhance the stiffness and durability of the bitumen.

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